

# (12) UK Patent Application (19) GB (11) 2 372 271 (13) A

(43) Date of A Publication 21.08.2002

(21) Application No 0202823.1

(22) Date of Filing 07.02.2002

(30) Priority Data  
(31) 0103576 (32) 14.02.2001 (33) GB

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(51) INT CL<sup>7</sup>  
**E21B 43/12 43/20**

(52) UK CL (Edition T )  
**E1F FLM FMU**

(56) Documents Cited  
**GB 2358202 A** **GB 2324108 A**  
**US 6056054 A**

(58) Field of Search  
UK CL (Edition T ) **E1F FLM FMU**  
INT CL<sup>7</sup> **E21B 43/12 43/20**  
**EPODOC, WPI, JAPIO**

(54) Abstract Title  
**Downhole pump driven by injection water**

(57) A method of enhancing hydrocarbon production involves pumping injection water down a wellbore to drive a downhole pump assembly (13) and using the pump assembly (13) to increase the production rate of hydrocarbons from the well. The injection water, after driving the pump assembly (13), exits through outlets (25) below a packer (17) and enters the injection zone (19) thereby driving hydrocarbons into the pump assembly (13) initially through inlets (10). The pump assembly (13) includes a turbine unit (12) driven by the movement of the injection water over turbine blades (32, fig 2).

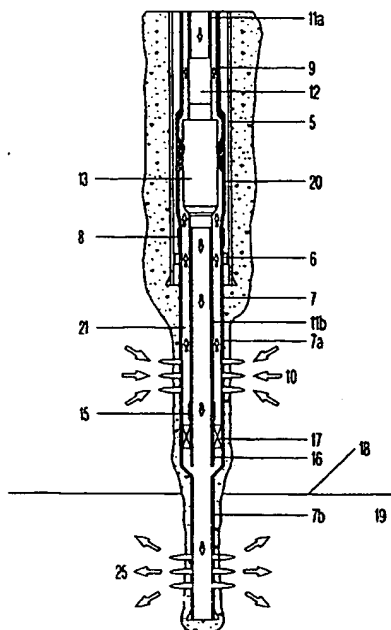
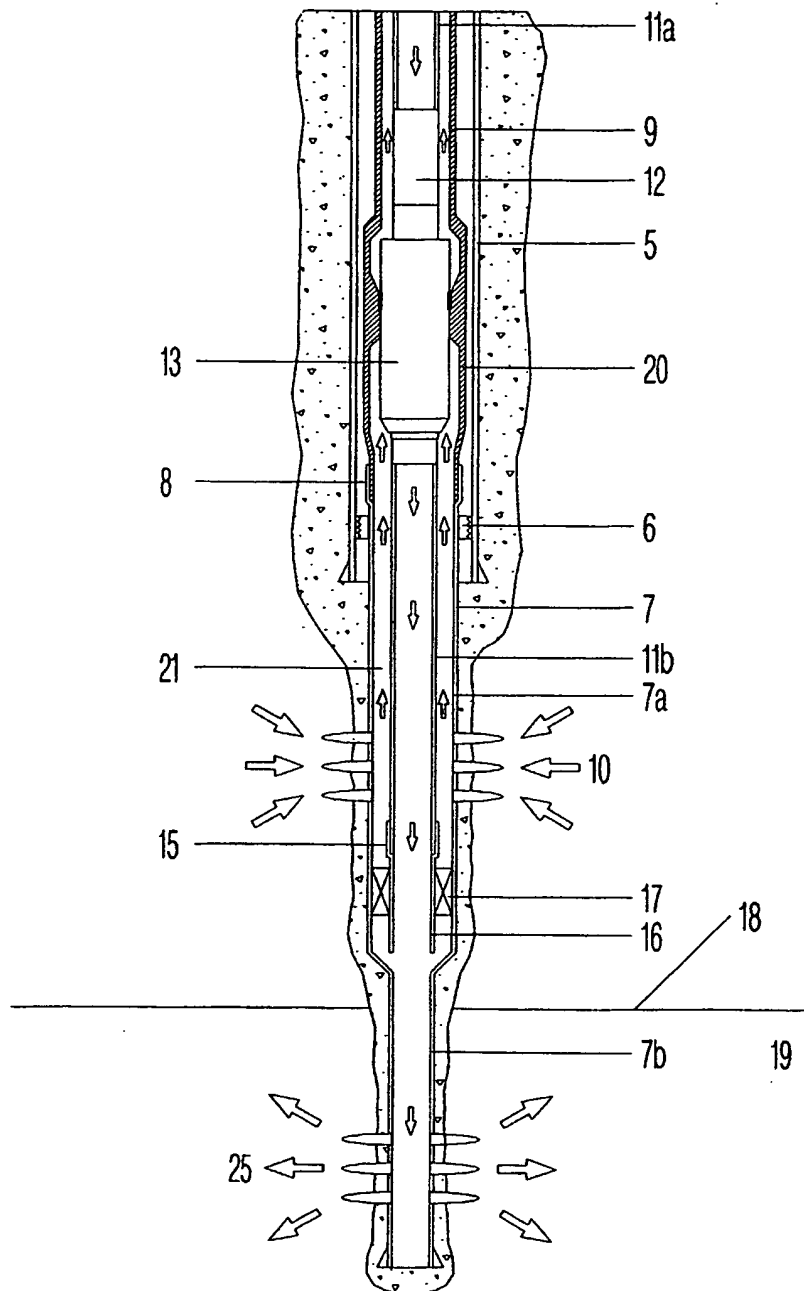
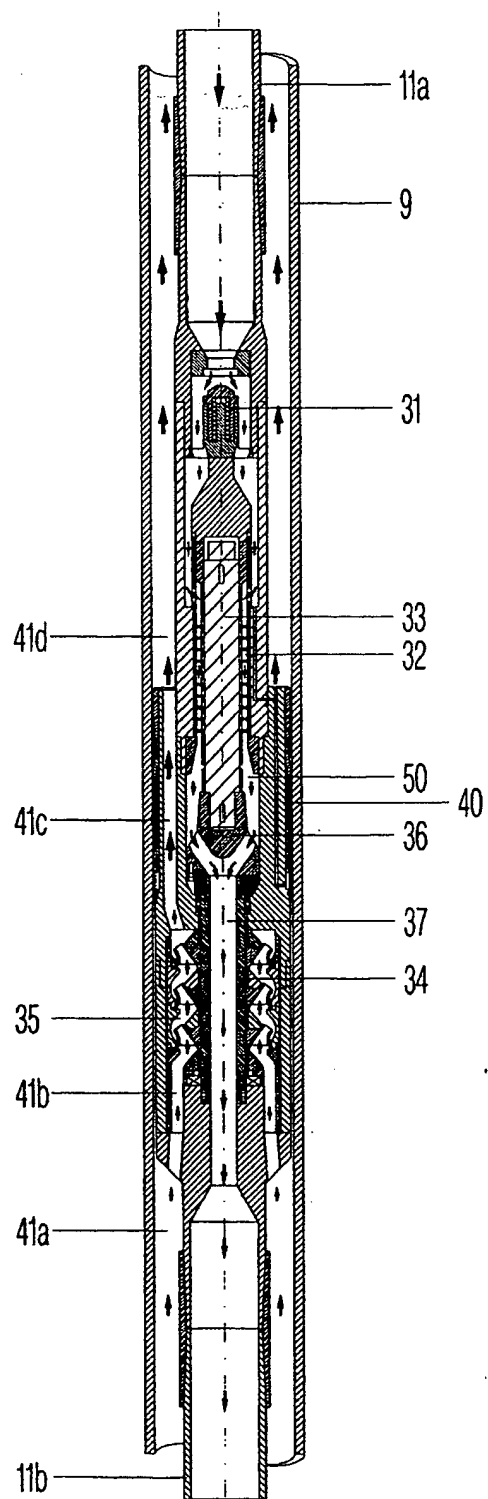


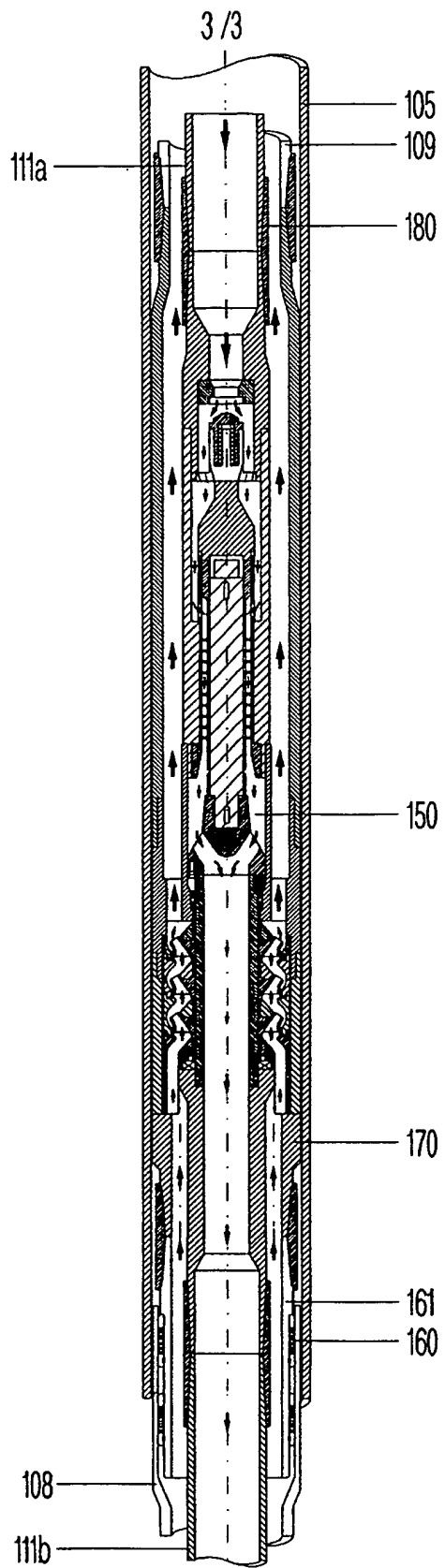
Fig. 1

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**Fig. 1**



**Fig. 2**



**Fig. 3**

1     **"DOWNHOLE PUMP"**

2

3     The present invention relates to a pump, and  
4     particularly one to be installed downhole for  
5     recovery of hydrocarbon fluids from drilled wells,  
6     and for the injection of fluids such as water into  
7     such wells in order to stimulate the production of  
8     fluid hydrocarbons therefrom.

9

10    Oilfield reservoirs generally consist of a layer of  
11    hydrocarbon fluids such as oil which lies on top of  
12    a denser layer of water called the aquifer. In low  
13    pressure wells or wells which have been produced for  
14    a number of years and which no longer have  
15    sufficient natural pressure to allow unaided flow of  
16    hydrocarbons from the reservoir payzone to surface,  
17    it is conventionally known to inject water into the  
18    underlying aquifer in order to maintain or increase  
19    the pressure in the reservoir and to enhance the  
20    flow of hydrocarbon fluids into a wellbore.

21

22    According to the present invention there is provided  
23    a pump for drawing a first fluid from a first end of  
24    the pump to a second end, the pump being powered by  
25    the flow of a drive fluid from the second end to the  
26    first, wherein the first fluid and the drive fluid  
27    flow through separate conduits, one of the conduits  
28    being located within the other.

29

1 The said one conduit is preferably entirely  
2 contained within the said other conduit.

3  
4 In the pump of the invention, the drive fluid  
5 preferably goes through a first conduit, and the  
6 produced first fluid goes through the other in the  
7 opposite direction. The pump of the invention  
8 therefore avoids crossover of drive and produced  
9 fluids in the body of the pump. Certain embodiments  
10 can also minimise the complexity of downhole  
11 completion.

12  
13 In a preferred embodiment of the invention, the  
14 drive fluid passes down an inner conduit, and the  
15 produced fluid passes up the annulus between the  
16 inner conduit and an outer tube. The blades of a  
17 turbine are preferably disposed in the path of the  
18 inner conduit and the turbine preferably provides  
19 power to a shaft which powers a pump driving the  
20 produced fluids up through the outer annulus.  
21 However, the drive fluid could equally pass through  
22 the outer annulus, and the production fluid could  
23 pass through the inner conduit. The pump in the  
24 outer annulus can be a centrifugal pump.

25  
26 An embodiment of the invention will now be described  
27 by way of example and with reference to the  
28 accompanying drawings in which;

29 Fig. 1 shows a schematic diagram of a pump of  
30 the present invention;

31 Fig. 2 shows a sectional view of a pump of  
32 another embodiment;

1            Fig. 3 shows a sectional view of a third  
2            embodiment of a pump according to the  
3            invention.

4  
5            Referring now to the drawings, the well schematic  
6            shown in Fig. 1 comprises a borehole lined with  
7            casing 5 which is cemented in place in the borehole  
8            in a conventional manner. A tapered liner 7, of  
9            which 7a and 7b are the upper and lower sections, is  
10           hung off from casing 5 by a liner hanger 6, is  
11           cemented in situ and perforated at 10 in a reservoir  
12           payzone allowing ingress of hydrocarbon fluids, and  
13           is additionally perforated at its furthest extremity  
14           25 to allow injection of water or other liqueous  
15           fluids into an aquifer 19. The liner 7 terminates  
16           at its upper end in a polished bore receptacle 8, in  
17           which is received the lower end of a tieback tubing  
18           string 9 which includes a dedicated sealing/locking  
19           element 20, known in the industry as a nipple. The  
20           liner 7, nipple 20 and tieback tubing 9 provide an  
21           outer string in which is disposed tubing 11a, a  
22           turbine sub 12, a pump body 13 located in the nipple  
23           20 and injection tubing 11b which is received in the  
24           polished-bore receptacle 15 of a packer shoe 16  
25           sealed by packer 17 to the cemented liner at the  
26           lower end of section 7a between the perforations 10  
27           and 25. Use of PBRs facilitates installation and  
28           retrieval of injection tubing for maintenance etc.  
29  
30           The bore of the turbine sub 12, pump body 13, the  
31           injection string of 11a and 11b, packer shoe 16 and  
32           section 7b of liner 7 provide an inner injection

1 conduit located within the outer annular conduit.  
2 The outer wall of the outer flow conduit comprises  
3 the upper section 7a of liner 7, the outer wall of  
4 the pump body 13 sealed against nipple 20 and  
5 tieback tubing 9. The inner injection string is  
6 located wholly within the bore of the outer string,  
7 and is provided for the injection of aqueous fluid  
8 such as water to the perforations 12 located in the  
9 aquifer 19 below the oil/water interface 18 and  
10 horizontally distant from the production  
11 perforations 10 so as to reduce the propensity to  
12 coning. The outlet of the inner injection string is  
13 located below the packers 17 thus preventing leakage  
14 of water from the injection string back up the  
15 annulus.  
16  
17 The outer wall of the annular conduit comprising the  
18 cemented liner 7 and tieback tubing 9 including  
19 nipple 20 directs produced fluids entering the  
20 annulus 21 through perforations 10 up said annulus  
21 21, through the pump body 13 and thence to surface.  
22 Injection of water through the inner injection  
23 string and lower perforations 25 below the oil water  
24 interface 18 maintains the pressure of hydrocarbon  
25 fluids entering the outer recovery string through  
26 upper perforations 10 where the reservoir and  
27 aquifer are in contact, and maximises recovery of  
28 produced fluids from the outer annulus.  
29  
30 In the embodiment shown in Fig. 2, the bore of a  
31 tieback tubing string 9 houses a single inner string  
32 of tubulars 11a and 11b for injection of fluids and



1 the annulus is provided between the inner string and  
2 the tieback tubing string 9. It is noted that there  
3 is no nipple in the tieback tubing string 9.

4  
5 Tubing 11a is attached to the pump assembly in which  
6 is established a check valve sub-assembly 31.  
7 Opening of the check valve 31 allows flow of  
8 injected fluid through to a turbine assembly in  
9 which the flow of fluid is directed into the path of  
10 a number of turbine blade stages 32. Flow of fluid  
11 across the blades 32 causes rotation of the solid  
12 shaft 33, which drives a pump shaft 34 on which are  
13 mounted impeller stages 35. The respective shafts  
14 are mechanically connected by flow coupling 36, said  
15 flow coupling also providing passage for fluids  
16 leaving the turbine stage through to the pump shaft  
17 34 which is hollow. The flow coupling is an  
18 important preferred feature of the invention as it  
19 can simultaneously entrain the pump shaft 34 from  
20 the turbine shaft 33, and ensures continuity of flow  
21 from the turbine exhaust chamber 50 through the bore  
22 37 of pump shaft 34. The flow holes through the  
23 flow coupling would preferably be shaped in the  
24 manner of an impeller. Fluids leaving the turbine  
25 blades 32 are directed into the bore 37 of the pump  
26 shaft 34, said bore being in flow connection with  
27 the lower tubing string 11b leading to a lower  
28 injection point into the aquifer (see Fig. 1).

29  
30 The tieback string 9 is preferably landed in the  
31 Xmas tree by a hanger at its upper extremity, and is  
32 set in the polished bore receptacle of a tapered

1 liner at its lower extremity. A practical  
2 alternative to the polished bore receptacle is use  
3 of a packer. It is to the bore of string 9 that the  
4 pump assembly preferably seals. The method of Fig.  
5 1 uses an external seal, typically in the form of  
6 chevron packing, set in a dedicated receptacle of a  
7 nipple type readily available to the industry. The  
8 preferred embodiment of Fig. 2 is of a pressure-  
9 activated external packer and slip system made  
10 integral with, or attached to, the pump assembly.  
11 The pump assembly is shown locked and sealed to the  
12 tieback string 9 by a slips/seal packer. The pump  
13 provides an annular flow path for produced fluids in  
14 complete isolation from the injection fluids.  
15 Produced fluids passing up the production annulus  
16 41a enter the pump at 41b, are directed into the  
17 pump impellers 35 and flow thence to surface through  
18 pump exit 41c and upper annulus 41d.  
19  
20 The slips/seal packer assembly 40 is a standard item  
21 in the industry and may be set mechanically or  
22 hydraulically. The advantage in providing a packer  
23 40 is that the pump can be set at any desired depth  
24 within in the tieback tubing string 9. The  
25 embodiment of Fig. 2 allows the drive fluid pressure  
26 to be used to set the packer 40 although 'hot  
27 lines'- small bore tubing - may be run to the packer  
28 from surface to provide setting and unsetting  
29 pressures.  
30  
31

1 The modified embodiment of the invention as shown in  
2 Fig. 3 has many similar components and will be  
3 referred to for ease of reference using the same  
4 numbering system but with 100 added where required  
5 by context. Inside the body of the pump, the  
6 mechanical components function in essentially the  
7 same manner as those featured in Fig. 2 and shall  
8 only be described by exception. The principal  
9 differences are the configurations of the tubular  
10 and sealing elements. The size of the pump is  
11 limited by the internal diameter of the outer  
12 tubular within which the pump assembly and its  
13 associated tubulars and seals must be run and set. A  
14 pump assembly attached at its upper end to a tieback  
15 tubing string 109 is installed within a cemented  
16 casing string 105, the tieback tubing string being  
17 hung at the wellhead. The lower end of the pump  
18 assembly has chevron seal elements 160 carried on a  
19 spacer string 161, the length of the spacer string  
20 being determined by operational requirements. For  
21 brevity, spacer string 161 is shown as a single  
22 item. The chevron seals set the polished-bore  
23 receptacle 108 which is sited at the top of the  
24 liner - not shown but corresponds to item 7 of Fig.  
25 1. An alternative method of achieving the lower seal  
26 for the pump is to use a packer to replace the PBR.  
27 Tubular 111b, which is attached to the inner  
28 connection of lower body 170 of the pump, extends to  
29 an inner PBR - not shown but corresponds to item 15  
30 of Fig. 1. After the pump assembly has been  
31 installed in the well, tubing 111a is run from the  
32 wellhead and attached the pump assembly's upper,

1 inner connection by a lock/seal system of which many  
2 are available within the industry. It is seen on  
3 Fig. 3 that the flow system is essentially the same  
4 as that of Figs 1 and 2 but the size of the pump,  
5 where the same tubular program is used on all  
6 embodiments, is significantly increased owing to the  
7 limiting size being that of the casing 5 or 105 as  
8 referred to in Figs 1 and 3 respectively.

9

10

11 From this present embodiment it will be evident that  
12 modifications could be made to the basic system  
13 which enhance its installation and operation under  
14 various circumstances. Due to the flow coupling  
15 having a possible castellated mating form to the  
16 pump shaft 34 then the turbine unit could be  
17 separately installable/retrievable/replaceable by  
18 wireline or coiled tubing to suit the pump duty as  
19 downhole conditions vary with time.

20

21 Tubular goods sizes for drilling and completion of  
22 oil wells vary for different geographical locations  
23 and it should be noted that any sizes shown or cited  
24 herein are typically used in the North Sea and  
25 should not be construed in any limiting sense.

26

27 The assemblies of Figs. 1 to 3 can be located at any  
28 desired depth in the well within casing string 5  
29 which determines the maximum pump diameter. These  
30 embodiments provide an outer annulus for recovery of  
31 produced fluids and an inner bore for injection of a  
32 drive fluid to power the turbines and also for

1 injection of fluid into the aquifer to increase  
2 recovery of produced fluids from the payzone of a  
3 formation. The drive fluid exhausts through the pump  
4 into a targeted injection zone within the aquifer.

5  
6 It is also possible that very high pressure fluids  
7 from a deep-set abnormally pressured reservoir would  
8 provide the drive fluid to a turbine thus providing  
9 power to a pump to drive a pump for a lower pressure  
10 reservoir sited some distance above the former.  
11 This system would act as a pressure exchanger with  
12 both fluids being produced to surface.

13  
14 Seals, although depicted and described as chevron  
15 types, can be of any desired type typically employed  
16 in the industry.

17  
18 It should be noted that for clarity no details of  
19 shaft bearings have been shown in the drawings.  
20 However, pump shaft design and bearings therefor are  
21 well established and known to those in the art.

22  
23 It is an especially preferred embodiment of the  
24 invention to provide a seal system such as a packer  
25 on a portion of the inner string so as to facilitate  
26 the sealing of the inner string or a chosen location  
27 within the outer string.

28  
29 In certain cases, the origin of the produced fluids  
30 may be multilateral branches drilled through and out  
31 of the main well bore rather than perforations in  
32 the tie back tubing.

1  
2  
3 It is anticipated that for fractured or segmented  
4 reservoirs and aquifers, the injected and produced  
5 fluids would not necessarily enter into or originate  
6 from the aquifer and reservoir of a given oil-water  
7 contact. Geological factors could dictate that the  
8 injection fluid would preferably target the aquifer  
9 beneath a neighbouring reservoir separated from that  
10 of the well by an isolating fracture.

11

12

1     CLAIMS

2

- 3     1. A method and apparatus for enhanced, combined  
4       hydrocarbon production and water injection  
5       operations in a single well wherein the method  
6       comprises:  
7       pumping injection water down the well to drive a  
8       hydraulic turbine unit within a downhole pump  
9       assembly;  
10      utilising the pump unit to increase the  
11      production rate of hydrocarbons from the well;  
12      ensuring passage of the injection water directly  
13      through the pump unit on exhausting from the  
14      turbine en route to the injection zone;
- 15    2. The apparatus of claim 1 comprising:  
16      an inner tubing string running from the tubing  
17      hanger set in the Christmas tree at the wellhead  
18      to the downhole liner;  
19      an outer tubing string running from the tubing  
20      hanger set in the Christmas tree at the wellhead  
21      to the downhole liner;  
22      a pump assembly provided by appropriate threaded  
23      connections as part of the inner tubing string.
- 24    3. The pump assembly of claims 1 and 2  
25      characterised, in combination, by:  
26      a packoff and slips module;  
27      a hydraulic rotary turbine mounted on and  
28      assembled to a solid shaft;  
29      a hydraulic rotary pump of which the constituent  
30      impeller stages are mounted on and assembled to a  
31      hollow shaft;

- 1 a flow coupling linking the solid shaft of the  
2 turbine to the hollow shaft of the pump;  
3 a check valve set in the assembly above the  
4 turbine unit.
- 5 4. The flow coupling of claim 3 which provides a  
6 mechanical link from the solid shaft of the  
7 turbine unit to the hollow shaft of the pump unit  
8 and further permits passage of the fluid  
9 exhausting from the turbine unit through to said  
10 hollow shaft of the pump unit.
- 11 5. The hollow shaft of any preceding claims to which  
12 the impeller elements of the pump are fixed and  
13 through which shaft the injection fluid passes to  
14 the attached injection tubing.
- 15 6. The packoff and slips module of claim 3 which  
16 seals and locks against the bore of the outer  
17 tubing string.
- 18 7. The inner tubing string of claim 2 which runs  
19 from a tubing hanger at the wellhead to an  
20 injection packer set within the downhole liner at  
21 a position below the production flow entry  
22 point(s) to the well, and of which tubing string  
23 the pump assembly is an element set at a depth  
24 appropriate to reservoir performance  
25 characteristics.
- 26 8. The method of any preceding claims whereby  
27 hydrocarbons emanating from the production zone  
28 of the well and thus being present in the lower  
29 annulus formed by the inner and outer tubing  
30 strings enter the pump unit at the local pressure  
31 and pass through the impeller stages to be  
32 discharged from the pump unit at an elevated



1        pressure into the upper annulus with the packoff  
2        ensuring separation of the high and low pressure  
3        fluids across the pump.  
4    9. The apparatus of claim 2 wherein the pump  
5        assembly is provided as part of the outer tubing  
6        string.  
7    10. The apparatus of claims 2 and 9 wherein the lower  
8        inner tubing string runs from the pump assembly  
9        to the injection packer.  
10   11. The apparatus of claims 2, 9 and 10 wherein the  
11        upper inner tubing string is a separate item run  
12        from the wellhead to the pump assembly subsequent  
13        to the installation downhole of the outer tubing  
14        string of claim 9.  
15  
16  
17  
18

Amendments to the claims have been filed as follows

- 2
- 3 1. A method for enhanced, combined hydrocarbon  
4 production and water injection operations in a  
5 single well wherein the method comprises:  
6 pumping injection water down the well to drive a  
7 hydraulic turbine unit within a downhole pump  
8 assembly;  
9 utilising the pump unit to increase the  
10 production rate of hydrocarbons from the well;  
11 ensuring passage of the injection water directly  
12 through the pump unit on exhausting from the  
13 turbine en route to the injection zone;
- 14 2. An apparatus to ensure the good operation of the  
15 method of claim 1 comprising:  
16 an inner tubing string running from the tubing  
17 hanger set in the Christmas tree at the wellhead  
18 to the downhole liner;  
19 an outer tubing string running from the tubing  
20 hanger set in the Christmas tree at the wellhead  
21 to the downhole liner;  
22 a pump assembly provided by appropriate threaded  
23 connections as part of the inner tubing string.
- 24 3. The pump assembly of claim 2 further  
25 characterised, in combination, by:  
26 a packoff and slips module;  
27 a hydraulic rotary turbine mounted on and  
28 assembled to a solid shaft;  
29 a hydraulic rotary pump of which the constituent  
30 impeller stages are mounted on and assembled to a  
31 hollow shaft;

- 1 a flow coupling linking the solid shaft of the  
2 turbine to the hollow shaft of the pump;  
3 a check valve set in the assembly above the  
4 turbine unit.
- 5 4. The flow coupling of claim 3 which provides a  
6 mechanical link from the solid shaft of the  
7 turbine unit to the hollow shaft of the pump unit  
8 and further permits passage of the fluid  
9 exhausting from the turbine unit through to said  
10 hollow shaft of the pump unit.
- 11 5. The hollow shaft of any preceding claims to which  
12 the impeller elements of the pump are fixed and  
13 through which shaft the injection fluid passes to  
14 the attached injection tubing.
- 15 6. The packoff and slips module of claim 3 which  
16 seals and locks against the bore of the outer  
17 tubing string.
- 18 7. The inner tubing string of claim 2 which runs  
19 from a tubing hanger at the wellhead to an  
20 injection packer set within the downhole liner at  
21 a position below the production flow entry  
22 point(s) to the well, and of which tubing string  
23 the pump assembly is an element set at a depth  
24 appropriate to reservoir performance  
25 characteristics.
- 26 8. The method of any preceding claims whereby  
27 hydrocarbons emanating from the production zone  
28 of the well and thus being present in the lower  
29 annulus formed by the inner and outer tubing  
30 strings enter the pump unit at the local pressure  
31 and pass through the impeller stages to be  
32 discharged from the pump unit at an elevated

1 pressure into the upper annulus with the packoff  
2 ensuring separation of the high and low pressure  
3 fluids across the pump.

4 9. The apparatus of claim 2 wherein the pump  
5 assembly is provided as part of the outer tubing  
6 string.

7 10. The apparatus of claims 2 and 9 wherein the lower  
8 inner tubing string runs from the pump assembly  
9 to the injection packer.

10 11. The apparatus of claims 2, 9 and 10 wherein the  
11 upper inner tubing string is a separate item run  
12 from the wellhead to the pump assembly subsequent  
13 to the installation downhole of the outer tubing  
14 string of claim 9.

15

16

17

18



Application No: GB 0202823.1  
Claims searched: 1-11

Examiner: Dr. Lyndon Ellis  
Date of search: 6 June 2002

## Patents Act 1977 Search Report under Section 17

### Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.T): E1F FLM, FMU

Int Cl (Ed.7): E21B

Other: Online: EPODOC, WPI, JAPIO

### Documents considered to be relevant:

Category	Identity of document and relevant passage	Relevant to claims
X, P	GB 2358202 A (Mentor) Whole document, noting fig 2 and page 3, lines 21 to page 4, line 19	1 at least
X	GB 2324108 A (Weir) Whole document	1-11
A	US 6056054 (Atlantic)	-

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.

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